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ON THE GRADIENT OF TIME-DISTANCE CURVE OF SEISMIC *P* WAVE (PRELIMINARY REPORT)

BY

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The existing travel-time tables are all well constructed as for the reference to routine observation. But it is doubtful whether the derivatives of time-distance curve calculated from these tables which play an important rôle in the theory of the internal constitution of the earth are correct or not. Then it is desirable to get the derivative *directly* from earthquake observations.

Fig. 1 shows the geographical distribution of the epicenters of *normal* earthquekes occurred during the International Geophysical Year.

The epicentral distances from respective epicenter to five seismological stations—Sendai, Tsukubasan, Matsushiro, Abuyama, and Nagasaki—in Japan can be calculated. The arrival times of seismic *P* wave at these stations have been reported in the given form. Then

$$\frac{dt}{d\Delta} \sim \frac{t_m - t_n}{\Delta_m - \Delta_n}$$

can be estimated for every pair of the stations. For an earthquake in which the *P* wave was observed at all the five stations the number of estimated $dt/d\Delta$ reaches to ten. The arrival times observed by different seismometers do not always coincide each other, even when an earthquake is observed at the same place. Therefore, we take the arrival times recorded by all the seismometers into consideration. Then, for an earthquake in which the *P* wave was observed by many seismometers the number of estimated $dt/d\Delta$ are numerous. In case of the distant earthquake, the horizontal seismometer has a tendency to record

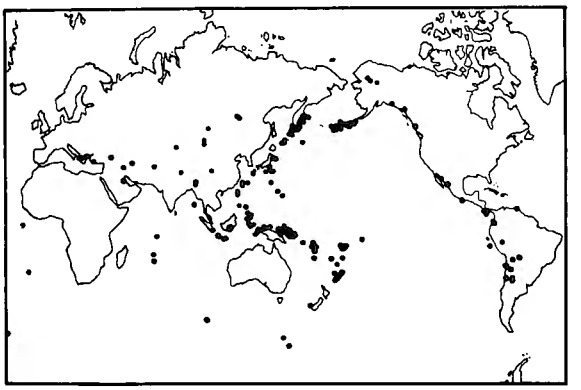

Fig. 1 Geographical distribution of the epicenters of normal earthquakes occurred during the I.G.Y.

the seismic P wave somewhat later than the vertical one. Then, we do not take up the data based on the horizontal seismometer. The result of calculation of $dt/d\Delta$ is shown in Fig. 2.

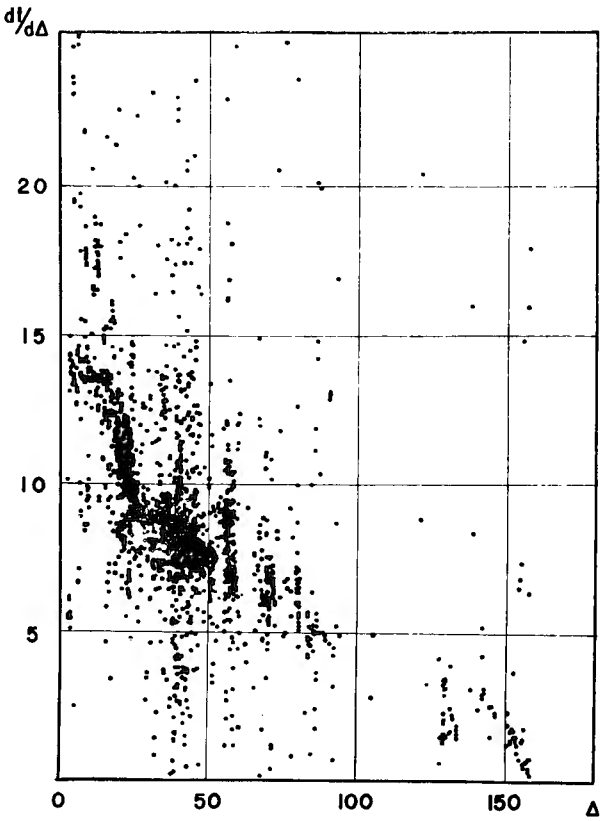

Fig. 2 Calculated $dt/d\Delta$ from the reports and the epicentral distances, without any consideration on the causes of errors.

The calculated values scatter considerably around their probable values. We now consider the causes of errors in the estimated values.

First of all, we take up the error due to the position of epicenter relative to a pair of stations. This error consists of two parts. One depends mainly on the uncertainty of epicenter—$\varepsilon(\delta\Delta)/\delta\Delta$—, and the other on the observational errors at the two stations concerned—$\varepsilon(\delta t)\delta t$—, although both of these errors increase when the epicenter approaches to the bisector of a pair of stations. When we take $0.^{\circ}5$ as the uncertainty of the position of epicenter and $0.^{s}5$ as the observational error of one observation, the error due to the relative position of epicenter and a pair

of stations can be calculated for all normal earthquakes and for each pair of the seismological stations. We exclude the earthquakes for which the error of calculated $dt/d\Delta$ may be in over than 5%. The epicenters exclued are shown in Fig. 3 as small circles.

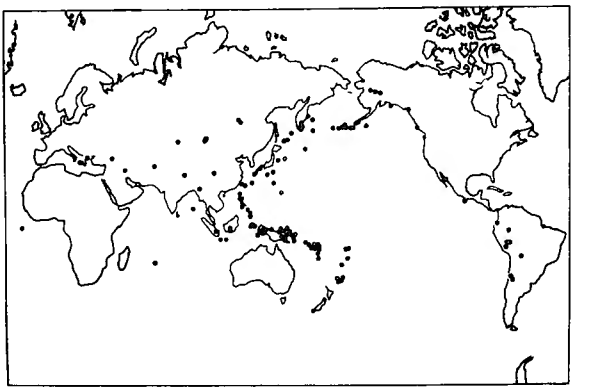

Fig. 3 Small circles show the epicenters inapt for the determination of $dt/d\Delta$.

Next, we consider the following three causes.

1. Focal depth. This effect is predominant in small distance.
2. Unequal difference of $\delta\Delta \sim \Delta_m - \Delta_n$ in $dt/d\Delta$. This effect is predominant where the slope of time-distance curve changes much.
3. Errors of travel-time tables by which the above two effects are evaluated. Jeffreys-Bullen's tables (1958) were adopted as the reference tables and the difference between this tables and Gutenberg's tables (1953) were used to limit the error due to the reference tables.

The evaluations of errors stated above are surmmarized in Table 1. Next step is

Table 1. Errors of estimated $dt/d\Delta$ due to (1) position of epicenter relative to stations, (2) focal depth, (3) distance interval, and (4) reference tables.

Distances (degrees)	errors (sec/deg)				
	(1)	(2)	(3)	(4)	total
6.0	0.71	0.33	0.01	0.35	1.40
8.0	0.70	0.32	0.03	1.15	2.20
10.0	0.69	0.32	0.10	0.80	1.91
12.5	0.67	0.26	0.08	0.26	1.27
13.5	0.66	0.28	0.07	0.46	1.47
14.5	0.66	0.28	0.15	0.28	1.37
15.5	0.65	0.19	0.25	0.11	1.20
16.5	0.63	0.42	0.29	0.16	1.50
17.5	0.63	0.56	0.54	0.30	2.03
18.5	0.62	0.52	0.69	0.16	1.99
19.5	0.55	0.50	0.27	0.06	1.38
20.5	0.52	0.54	0.53	0.10	1.69
21.5	0.50	0.32	0.58	0.30	1.70
22.5	0.50	0.14	0.34	0.30	1.28
23.5	0.49	0.12	0.20	0.24	1.05
24.5	0.49	0.08	0.07	0.18	0.82
25.5	0.47	0.04	0.05	0.16	0.72
26.5	0.46	0.04	0.11	0.12	0.73
27.5	0.46	0.06	0.09	0.14	0.75

32.5	0.44	0.06	0.01	0.10	0.61
37.5	0.42	0.04	0.01	0.02	0.49
42.5	0.41	0.02	0.06	0.02	0.51
47.5	0.40	0.02	0.08	0.18	0.68
52.5	0.38	0.04	0.04	0.26	0.72
57.5	0.35	0.04	0.06	0.04	0.49
62.5	0.34	0.02	0.05	0.08	0.49
67.5	0.32	0.04	0.03	0.10	0.49
72.5	0.30	0.04	0.08	0.10	0.52
77.5	0.28	0.00	0.05	0.18	0.51
82.5	0.26	0.04	0.06	0.08	0.44
87.5	0.24	0.04	0.04	0.12	0.44
92.5	0.23	0.00	0.03	0.14	0.44

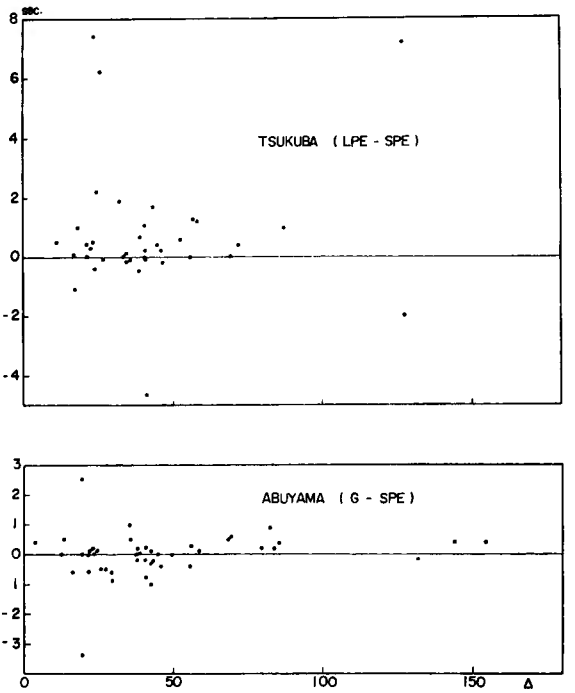

Fig. 4 Relations between the differences in the arrival times with seismometers and the epicentral distances.

to pick up the calculated values having residuels (referred to Jeffreys-Bullen's tables) larger than the total errors in Table 1, and then to exclude the data which contribute to these values picked up and do not to the rest at all.

The difference in the arrival times with seismometers used may be expected to depend upon the magnitude of earthquakes or the epicentral distances. But this relation is not clear as is shown, for example,in Fig. 4 in the case of long-period electromagnetic seismometer vs. short-period electromagnetic one at Tsukubasan and Galitzin seismometer vs. short-period electromagnetic one at Abuyama. Therefore, we neglect the magnitude or distance-effect. According to the reports from the stations, the differences in the arrival times with seismometers used during the I.G.Y. are as follows: In general, short period seismometer with high sensitivity is apt to record the first movement earlier than the others, but it could not be considered that the numerical values in Table 2 are significant. We consider, therefore, Table 2 as observation equations in order to reduce the arrival time by any seismometer to the one

by standard instrument. The result of calculation is shown in Table 3 when the short-period electromagnetic seismometers are adopted as standard ones. The delation and the correction stated above lead us to Fig. 5 from Fig. 2. More accu-

Table 2. Differences of arrival times.

stations	instruments	diff. arr. t.	numbers obs.
Tsukuba	*LPE-SPE*	0.67	41
	CLP-SPE	0.255	31
	CLP-LPE	−0.07	27
Matsushiro	*G-SPE*	0.21	15
	G-BS	0.67	3
	BL-SPE	0.0	1
	BL-BS	0.9	1
Abuyama	*G-W*	0.14	18
	G-SPE	−0.04	50
	W-SPE	0.02	28

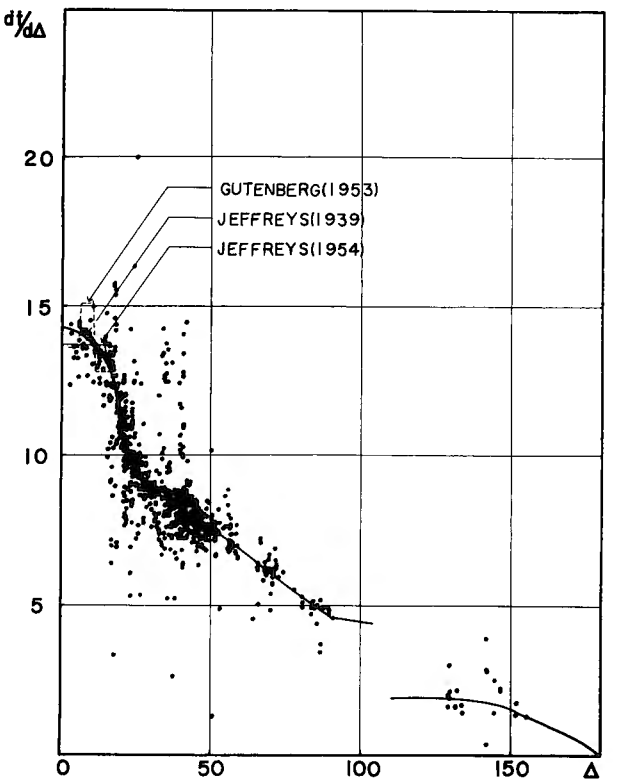

Fig. 5 Final result of the distribution of $dt/d\Delta$ with epicentral distance.

Table 3. Correction to the arrival times.

Tsukuba		Matsushiro		Abuyama	
SPE	0^s	*BS*	$0^s.53$	*W*	$0^s.06$
CLP	−0.37	*SPE*	0	*G*	0.00
LPE	−0.58	*BL*	−0.19	*SPE*	0
		G	−0.20		

rate rereadings of seismograms were carried out at Tsukubasan after the I.G.Y., so the numerical values in Table 2 and Table 3 should be corrected. We are now in the way of recalculations.

The calculations were performed by use of the electronic computer at Kyoto University (KDC-1). The programming and the operation were done by Mr. I. Hirano and Mr. Shimada. The punching and other calculations were by Miss F. Kawai. The writer wishes to say his hearty thanks to these people and to the staffs of the seismological stations—Sendai, Tsukbasan, Matsushiro, Abuyama and Nagasaki—.

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